INTERNATIONAL JOURNAL OF MANUFACTURING TECHNOLOGY AND INDUSTRIAL ENGINEERING (IJMTIE)
Vol. 1, No. 1, January-June 2011, pp. 79-84

ANALYSIS OF METAL FLOW BEHAVIOR DURING FRICTION WELDING OF TUBE TO TUBE PLATE USING AN EXTERNAL TOOL

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ABSTRACT: Several developments have been occurring in the field of materials processing. Welding is an important metal joining process that has varied industrial applications. Friction welding is widely used as a mass production method for fabrication in various industries. Friction welding of tube to tube plate using an external tool (FWTPET) is an innovative friction welding process which is capable of producing leak proof high quality weld joints with good mechanical properties. In the present study, FWTPET welds have been performed and metal flow analysis has been carried out by radiography test, brass insertion techniques and filler plate techniques. Based on the results obtained, the metal flow pattern has been observed and analyzed. On the basis of the conduct of all techniques, it has been found that the metal flows towards the center of tool axis, thereby ensuring defect free weld joints.

Keywords: Friction welding, FWTPET, Radiography test, Brass insertion techniques, Filler plate techniques, Metal flow pattern.

1. INTRODUCTION

Recently, in many industrial applications, much attention has been provided to aluminium because of various unique properties Friction welding is a method of manufacturing which is being used extensively in recent times due to advantages such as low heat input, production time, ease of manufacture and environment friendliness [1]. It is a solid phase welding process that joins two materials by the friction heat generated by the relative motion of the contact surfaces under the action of an upset pressure. Some of the disadvantages of fusion welding techniques such as high heat input and usage of non-matching filler wire can be avoided by using friction welding. However, conventional friction welding is not suitable to weld tube to tube plate. Friction welding of tube to tube plate using an external tool (FWTPET) was invented in the year 2006 by one of the present authors and patent was granted in the year 2008 [2]. FWTPET is a relatively new solid state welding process used for joining tube to tube plate of either similar or dissimilar materials with good mechanical properties such as hardness and tensile strength. Some important process parameters of FWTPET include tool rotational speed, shoulder diameter and clearance between pin and tube [3]. Metal flow analysis will be helpful for understanding and modeling of the process in orders to improve the performance [4]. Scant research has been reported on metal flow analysis in friction stir welding [5] but in the case of FWTPET process, there is no literature evidence for metal flow analysis as it is being recently invented. In addition, it is difficult to understand the mechanism involved behind bond formation. Hence, in the present work an attempt has been made to understand metal flow and principle behind bond formation.

2. EXPERIMENTAL WORK

The FWTPET machine developed in-house and the external tool is made of tool steel and consists of a shoulder and pin. The tube to tube weld joint is cleaned and holes are prepared along the faying surfaces of the tube. A suitable hole is drilled in a plate and the tube is fitted and the assembled in FWTPET machine table. FWTPET

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machine consists of tool holder, spindle, table and supporting structure. The tool is lowered during rotation and heat is generated due to friction when the shoulder touches the plate. The plastic flow of metal takes place towards the center of the tool axis. The metal flows through the holes in the tube and occupies the gap between pin and inner diameter of the tube. The tool is withdrawn after the predetermined time. The cylindrical pin restricts the material movement and pressure is applied between the tube and plate. The bonding takes place between faying surfaces which are at higher pressure and temperature. The process variables considered in this research study are tool rotational speed (1030 rpm), pin clearance (1 mm) and shoulder diameter (30 mm) [3]. Both the tube and plate used in the present study are made of commercially pure aluminum and its chemical composition is shown in Table 1.

Table 1
Chemical Composition of Commercially Pure Aluminum

	Element									
	Al	*Si*	*Fe*	*Cu*	*Mg*	*Mn*	*Ti*	*Zn*	*Cr*	*V*
Wt %	Bal	0.0006	0.0007	0.0013	0.0021	0.0001	0.0001	0.0002	0.0001	0.0001

The filler plate used in the present study is AA 2024 and its chemical composition is shown in Table 2. The experiment has been conducted using 6 mm rolled plates of commercially pure aluminum and cut into the required sizes (50 mm x 70 mm) by means of a power hacksaw. Similarly, tubes of 19 mm external diameters have been cut into required size (35 mm height).

Table 2
Chemical Composition of AA 2024

	Element								
	Al	*Si*	*Fe*	*Cu*	*Mg*	*Mn*	*Ti*	*Zn*	*Cr*
Wt %	Bal	0.5	0.50	4.5	1.6	0.7	0.15	0.25	0.10

This is followed by the drilling of 19 mm diameter holes in the rolled plate. Then the tubes are fixed in their respective hole position. The assembly of the work piece is clamped on the machine table and the tool has been fixed to the spindle of the machine. In this present study, three techniques such as radiography test brass sheet insertion technique and filler plate techniques are followed to determine the metal flow direction during FWTPET process. Before the conduct of radiography test, the steel ball (2 mm) is inserted around the circumference of the tube to tube plate at different positions as shown in Figure 1. The radiography test has been conducted after the completion of FWTPET process so as to identify the movement of steel ball and to ensure defect free weld. In the second technique, a brass sheet (1mm) is inserted along the faying surface of the tube as shown in Figure 2. The third filler plate technique has been used filler plate to arrange above the tube-plate before FWTPET process as shown in Figure 3. Finally, the metal flow analysis has been conducted using macro-and micro-structural observation after the completion of the FWTPET process.

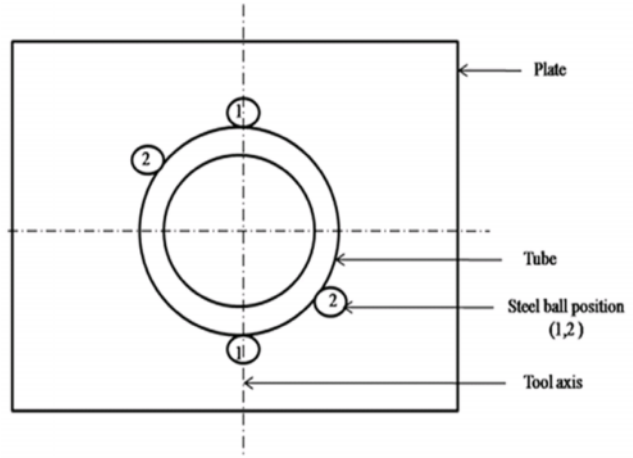

Figure 1: Position of Steel Ball Around the Tube to Tube Plate

Figure 2: Brass Sheet Attached to the Circumference of Tube

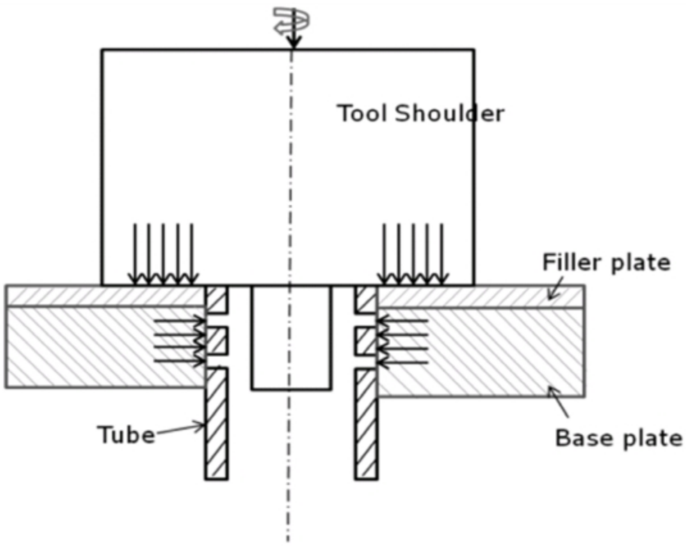

Figure 3: Filler Plate Arrangement

3. RESULTS AND DISCUSSIONS

3.1. Radiography Test

Radiography image of weld made by FWTPET with steel balls is shown in Figure 4. From the result it is clearly evident that the steel balls move towards the center of the tool axis. Due to the axial movement of the tool, heat is generated by the shoulder and the metal reaches the plastic condition. Experiments are repeated by keeping the steel balls at different positions around the tube to tube plate. Similar movement of balls towards the center axis as indicates by previous result is observed from the Figure 5 and Figure 6. From radiography test, it also observed that the weld joints are free from defects such as crack, porosity etc.

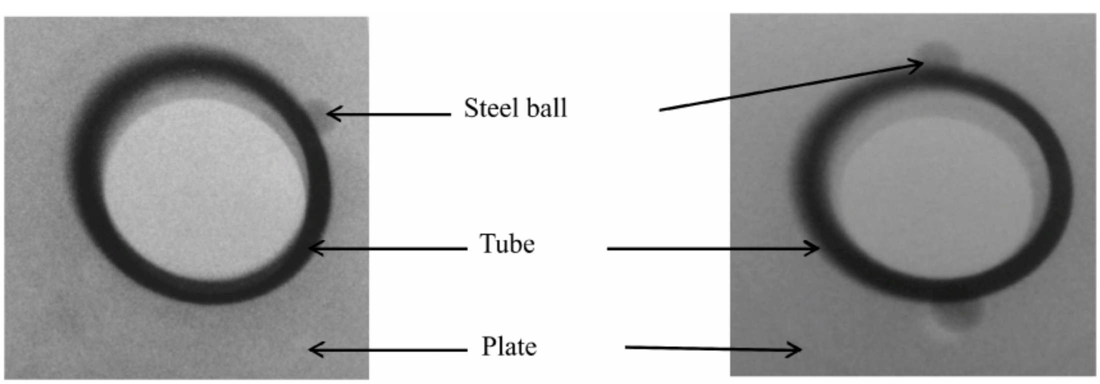

Figure 4: Result of Radiography Test
(Steel ball oriented in left diagonal position)

Figure 5: Result of Radiography Test
(Steel ball oriented in perpendicular position)

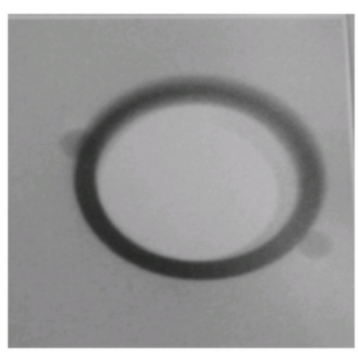

Figure 6: Result of Radiography Test (Steel ball oriented in right diagonal position)

3.2. Brass Sheet Insertion Techniques

Figure 7 and Figure 8 shows the macro and micro-structural observation of the FWTPET weld obtained with a brass sheet. From the macro and micro-structure, the metal flow has been observed gradually towards the center of the tool axis and this enables to achieve metallurgical bond between tube and tube plate. Based on the macro-structural observation, it is found that the weld condition of tube to tube plate can give defect free welds as shown in Figure 9.

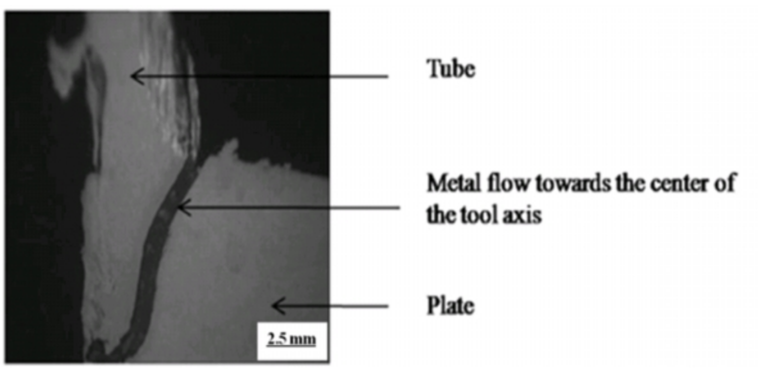

Figure 7: Macro-structural Observation of Metal Flow Analysis

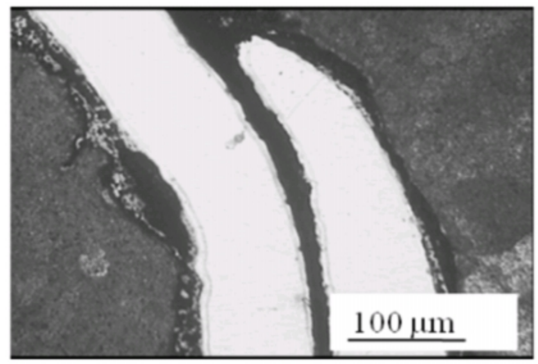

Figure 8: Microstructure Obtained by Brass Sheet Insertion Technique

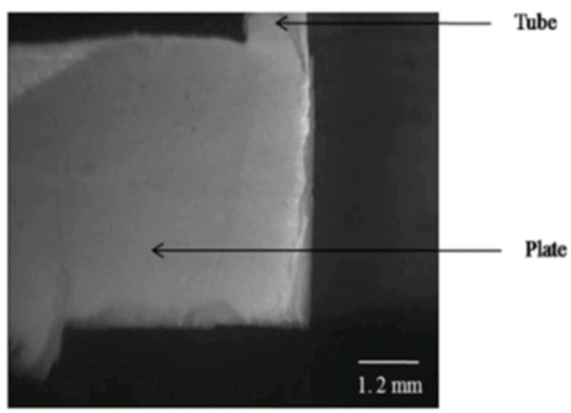

Figure 9: Macro-structural Observation of Tube to Tube Plate

3.3. Filler Plate Techniques

When the tool is lowered, the tool shoulder touches the filler plate, the metal in the base plate flows towards the centre of the tool axis and it flows through the holes on the periphery of the tube is shown in Figure 10.

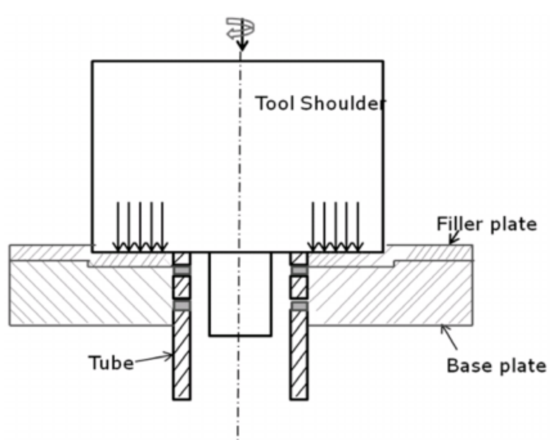

Figure 10: Tool Shoulder Contact with Filler Plate during FWTPET Process

As the tool is again lowered, the tool shoulder touches the base plate, the metal from filler plate flows towards the centre of the tool axis and occupies the space between the pin and inner portion of the tube is shown in Figure 11. Then the tool is lowered further, the filler plate is removed from the base plate and a small portion of the base plate flows towards the centre of the tool axis and occupies the space between the pin and tube is shown in Figure 12 and Figure 13 is clearly depicted the extra metal flow from filler plate towards the center of the tool axis.

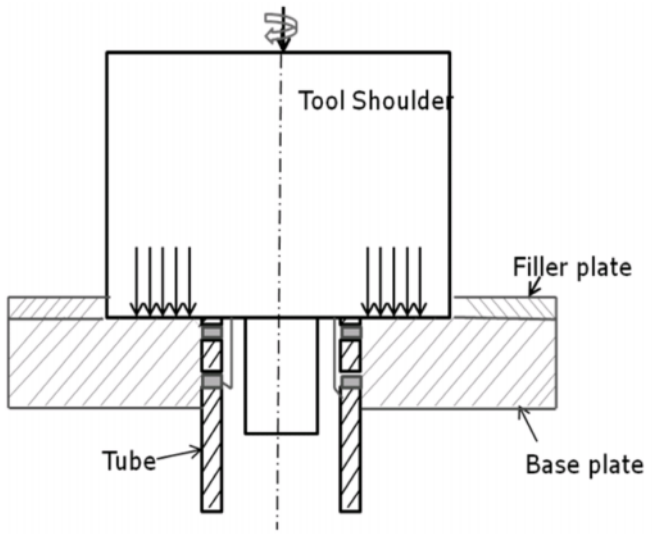

Figure 11: Metal Flow from Filler Plate during FWTPET Process

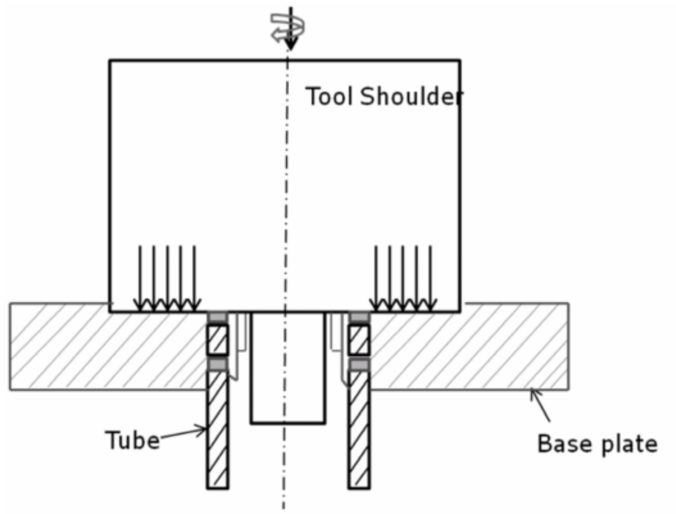

Figure 12: Extra Metal Flow from Base Plate during FWTPET Process

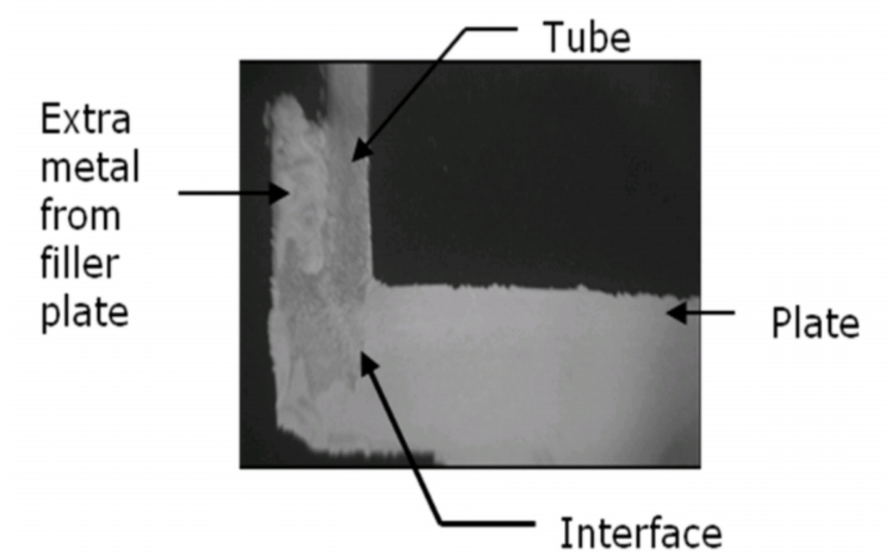

Figure 13: Macrostructure Observation after FWTPET Process

4. CONCLUSION

This paper reports the metal flow behavior during FWTPET process. The radiography test indicated that the steel balls move towards the center of the tool axis. From the result of radiography test, it has also been found that there is no crack, porosity and other defects. The macro and micro-structure analysis based on brass sheet insertion technique also confirms that the metal flow occurs towards the center of the tool axis. As the plate material surrounding the tube is moved towards the tool axis, a high pressure is created along the tube and plate interface. The filler plate technique has been observed the movement of metal flow towards the center of the tool axis. Hence, FWTPET process is suitable to make high quality defect free joints.

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